

HIGHWAY RESEARCH REPORT

INVESTIGATION OF A LASER BEAM TECHNIQUE FOR THE DETERMINATION OF SLOPE STABILITY

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DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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DIVISION OF HIGHWAYS

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June 1971

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

INVESTIGATION OF A LASER BEAM TECHNIQUE

for the

DETERMINATION OF SLOPE STABILITY

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Principal InvestigatorMarvin L. McCauley
Ronald W. Mearns
Co-InvestigatorsAssisted By
Paul Salinas
Thomas Hoover

Very truly yours,

A large, stylized handwritten signature of John L. Beaton, written in dark ink, with a long horizontal stroke extending to the left.
JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, Travis; McCauley, Marvin; and Mearns, Ronald.
"Investigation of a Laser Beam Technique for the
Determination of Slope Stability."

ABSTRACT: Equipment and a technique for detecting vibrations in a rock cut were developed. The technique utilized a reflected laser beam to achieve the necessary amplification.

Although laboratory and field tests indicate that detection of vibrations can be accomplished using the laser beam, no significant advantages over the standard electronic system were obtained. Also the vibrations detected by the laser could not be correlated with events detected by the electronic system and therefore could not be correlated directly to slope stability.

For this application and at this time the laser system studied does not appear to be useful.

KEY WORDS: Slope Stability, Rock Mechanics, Geophysics, Determination, Research.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. Bruce Meinders, Forest Engineer, U. S. Forest Service, El Dorado National Forest for providing the site used in the field portion of this study. Special thanks are also extended to the Forest Service personnel who provided essential help in the field.

This report presents the results of an attempt to detect instability in a rock cut slope using a reflected laser beam. The project was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration (Federal Program No. HPR-1(7) D-5-32).

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

In California, the construction of highways that meet interstate specifications has resulted in higher cuts and fills. The failure of one of these large earth structures is inconvenient, expensive, and frequently hazardous.

Previous work by Obert (1), Obert and Duvall (2), Beard (3), Goodman and Blake (4), and McCauley (5) indicate that slope failures are preceded by an increase in the rate of occurrence of sub-audible rock noise events. An existing FHWA financed research project (D-5-2) has resulted in development of equipment and a technique for detecting and analyzing sub-audible rock noise events. Several methods for utilizing such information have been field tested with good success. A final report on this project will be completed in the near future.

In order to perform the sub-audible rock noise work, it was necessary to walk to the location and to rely on sensitive transducers and high gain amplifiers. Access was often difficult and hazardous especially on unstable slopes. The transducers were fragile and sensitive to heat and moisture. The high gain amplifiers were sources of electronic noise which could mask sub-audible rock noise events and often contributed noises which could be mistaken for sub-audible rock noise.

Since the rate at which sub-audible rock noise events occur has proven useful in evaluating slope stability, a method of detection which might eliminate some of the above disadvantages was conceived and tested. This report describes a technique for detecting sub-audible rock noise events using a laser beam and summarizes the results of this research.

This new technique is applicable only to cut slopes in rock. It consists of attaching a reflector to the rock slope and using it to reflect a laser beam. A detector placed in the reflected beam would be used to detect deflections of the beam. The deflections occur when the mirror vibrates in response to the relatively low frequency sub-audible rock noises passing through the rock mass.

The anticipated advantages of such a system over existing systems are:

1. The slope only needs to be climbed once to install the reflector.
2. Amplification is accomplished by the length of the reflected beam, thus reducing electronic noise and interference.
3. The equipment can be more sophisticated and sensitive since it need not be portable, and can be powered by a generator.

CONCLUSIONS

The laser system described in this report is capable of detecting vibrations in a rock mass. However, extensive research would have to be completed to understand the nature of the detected vibrations and their relationship to slope stability. The potential advantages of such a system do not at this time warrant further research.

RECOMMENDATIONS

It is recommended that this project be terminated.

EQUIPMENT

Since this was an entirely new application for laser technology, selection of the various equipment components necessary to perform the work was a difficult task.

Laboratory type instruments were used, instead of instruments designed for field use, because they were cheaper and there was a much wider selection of laboratory instruments and accessories available, thus assuring the greatest probability of success.

It was decided that compatible components (i.e., made by the same manufacturer) would be used, again to assure the greatest probability of success, and to simplify purchasing procedures.

An extensive review of all available catalogs and brochures was made and two manufacturers, Spectra-Physics and Resalab, Inc., were visited. It was found that while there are numerous companies which are capable of providing equally satisfactory components only one company, Spectra Physics, was found which could provide the whole system.

Consultation with technical representatives of Spectra Physics resulted in selection of the following pieces of equipment:

1. Model 133 Helium Neon Laser (Plate 1);
2. Model 338 Collimating telescope with an adaptor to the laser (Plate 2);
3. Model 401C Power Meter (Plate 3);
4. Model 406 Center Detector (Plate 4);
5. 515-2 polarizing beam splitter (Plate 5).

Each of these items are standard Spectra Physics products. A 2" x 2" front surface laser reflector was purchased from Optics Technology (Plate 6) to be used as the field reflector. To facilitate alignment of the reflector, a universally adjustable camera mount was adapted to hold the mirror and to be attached to the face of a cut.

The output signals of the Power Meter, the Center Detector, and the ElectroVoice 805 contact microphone used in our electronic sub-audible rock noise equipment were amplified by a General Radio Model 1551C Sound Level Meter and recorded on a Roberts 6000 Stereo Tape Recorder for all experiments conducted as part of this study.

The noise events were analyzed by playing the tape back through a Brush oscillographic recorder giving a visible record of the relative amplitudes of the noise events and background noises.

LABORATORY TESTING

Laboratory tests were performed to determine the operating characteristics of the various components and to develop a technique for detecting noise events.

The laser was tested for stability and power output. These tests were conducted with the laser, with and without the collimating telescope, and the power output was measured with the power meter. It took approximately 10 minutes of warm-up for the laser to achieve maximum power output. The actual power ranged from .00125 Watts at the start to a maximum steady output of .00167 Watts after 10 minutes. This was found to be true even when the voltage provided to the power supply was varied from 100 to 125 volts. To summarize, this laser provides the necessary steady power after a 10 minute warm-up. All other experiments were performed after the necessary laser warm-up period.

Other facts learned during this first series of tests were:

1. There is a 50 percent loss of power at a distance of 150 feet from the laser when the collimating telescope was not used.
2. The collimating telescope could be focused only for distances greater than 50 feet.
3. The power at 50 feet without the telescope was .0016 Watts and with the telescope was .0012 Watts. However, the initial power loss in the telescope was compensated for by the capability of focusing the beam at all distances greater than 50 feet.

The second series of tests were performed to check the effectiveness and ease of use of the center detector and the power meter. It was determined that both instruments were effective in detecting vibrations of the laser beam but the center detector was considerably more difficult to use because the detector had to be centered on the beam and its axis had to be aligned with the beam for the best results.

Also, as part of this second series of tests, various attempts were made to generate interference which could complicate analysis of the rock noise events. Both detectors performed the same in these tests. The results of these tests were:

1. Wind (from a large fan) had no effect on the beam but could cause significant interference if directed on the laser, the reflector or the detector.
2. Objects, including water drops, passing through the beam created significant interference when they were about 1/8 inch or larger in diameter.
3. Heat waves from a bunsen burner three feet under the beam always caused significant interference.

The last series of laboratory tests were performed to develop a technique for detecting noise events and to compare the noise detecting capabilities of the laser system and the electronic system. The technique that was developed consisted of mounting the laser on a special bracket attached to a surveying transit. This permitted relatively rapid and stable instrument set ups, and also allowed easy aiming of the laser beam at the reflector. This laser mounted on the transit is shown in Plate 7. For laboratory tests, the reflector was mounted on a ring stand. For field work, an adjustable camera base was adapted to hold the reflector and to be attached to a bolt grouted into the rock cut. Adjustment of the mirror is required to reflect the beam back to the detector. A regular mirror was tested and found to reflect only about 50% of the power reflected by the front surface reflector.

The output of the center detector and the power meter was amplified with Model 1551C General Radio Sound Level Meters to provide sufficient signal strength to be recorded on a Roberts 6000 stereo tape recorder (Plate 8).

The noise detection experiments were performed in a light tunnel to eliminate light related interference. An ElectroVoice 805 contact microphone was placed adjacent to the laser reflector in order to obtain records which would permit comparison of the signal to noise ratios of the two systems (Plate 9). The noise events were generated by dropping small weights from a one foot height to the concrete floor of the light tunnel at different distances from the detectors. Results of this series of tests were:

1. The center detector was more sensitive than the power meter.
2. The laser system detected the noise events for a distance of 20 feet and the electronic system detected the noise for a distance of 85 feet.

3. For noise events originating close to the reflector the laser system has a higher signal to noise ratio, but this advantage is lost quickly as the distance increases.

In summary, the laboratory tests show that the laser system is capable of detecting noise events, but it is not as effective as the existing electronic system.

FIELD TESTING

Although the laser system was not as effective as had been anticipated, a field test of the system was performed as a check of laboratory results.

The cut selected for the field tests is located about 20 miles northeast of Placerville adjacent to the north abutment of Hell Hole Reservoir. This cut was selected because it was steep and high, because it had a strong potential for instability, and because it was in a remote area thus reducing the potential of man made electrical and physical interference.

The cut slope is approximately 2500 feet long and 200 feet high. The lower 50 feet of the cut is vertical and the remainder has a 1/4:1 slope. It was constructed using the presplitting controlled blasting technique. Plate 10 shows this cut. The flattened portion of the slope on the left is above the spillway. Flattening of this portion of the slope was required by the State Division of Dam Safety because of the potentially unstable slope. The fault surface to which the slope was flattened extends under the remainder of the cut and poses a threat to the U.S. Forest Service road that passes under the cut.

A portable gasoline powered generator was used to power the laser. The generator was kept from 60 to 100 feet away from the instrument and downwind as much as possible to reduce interference.

The first experiment performed at this location was to develop the instrument setup and technique necessary to use the laser in the field. The setup used, shown in Plate 11, consisted of the transit mounted laser with the collimating telescope and the beam splitter. One beam was deflected into the center detector to detect vibrations that originate at the laser, the second beam was reflected from the front surface reflector about 150 feet into the power meter. Simultaneous recording of the two signals using the equipment shown in Plate 8 permitted differentiation of noises originating at the laser and noises originating at the reflector.

The experiment was performed at midday, with a temperature of 85° and wind velocity ranging from 1 to 7 miles per hour. The

experiment was successful in that noise events were recorded that could have been sub-audible rock noise events. Three significant problems became apparent in this experiment:

1. Background noise caused by wind on the laser creates a highly variable background noise which complicates interpretation. The tripod mount for the laser is not sufficiently stable for field work.
2. The necessity to perfectly align the center detector axis with the laser beam makes the center detector an impractical field instrument.
3. Locating and positioning the reflected beam in sunlight is difficult and time-consuming, suggesting evening or nighttime operation.

The second experiment utilized the experience gained in the first experiment to provide more meaningful results. The work was done at about 5:00 p.m. which was late enough for the test area to be located entirely in shadow. The temperature was approximately 78° and the wind was 8 to 14 miles per hour with occasional calm periods. The power meter was used to detect the reflected beam and an ElectroVoice 805 was placed in intimate contact with the rock adjacent to the reflector. The equipment setup was as shown in Plate 9 except the Power Meter was connected to the second Sound Level Meter. To check the system, noises were generated by striking the rock near the reflector with a hammer. Analysis of these records again showed that wind caused background noise on the laser record, and that the electronic subaudible rock noise equipment had a better signal to noise ratio. A standard 15 minute rock noise recording was made. This recording yielded sub-audible rock noise event counts of 18 for the laser and 9 for the electronic equipment. Noise of the events recorded by either instrument could not be positively identified as corresponding to an event recorded by the other. Since all our knowledge and experience is based on noise event counts obtained by the electronic equipment, we were unable to meaningfully analyze the laser noise events. The rock noise count obtained with the electronic equipment indicated that the cut was stable. Working in shade greatly simplified the locating, positioning, and focusing of the reflected laser beam.

The third experiment was exactly like the second experiment except that it was conducted at 8:00 p.m. The temperature was about 65° and the wind velocity ranged from 0-2 miles per hour. The lack of wind eliminated the background noise problem with the laser records and resulted in a slightly better signal to noise ratio than with the electronic equipment. This observation is based on the artificially generated noise experiments. A standard 15 minute rock noise recording yielded noise counts of 35 for the laser and 7 for the electronic equipment. Again there was no positive correlation between noise events on the two different records.

The problem of locating, positioning and focusing the beam was negligible in this night experiment.

In summary, our field tests indicate that although the reflected laser beam technique does transmit and record noise events, they are different events than those which we have been able to correlate to slope stability in previous studies. Without an extensive study to determine the relationship between the laser detected events and slope stability, the records are, for practical purposes, useless.

In addition, the anticipated advantages, greater noise free amplification, less traversing of the slope and more sophisticated instrumentation, while more or less realized actually were the results of trade offs. While greater amplification was demonstrated at night, wind noise complicated interpretation. Alignment of the laser, reflector and detector could be accomplished fairly easy at night, but in practice the reflector had to be removed after each test in order to protect the reflecting surface from the weather and vandalism. It was therefore necessary that the slope be climbed each time just as with the electronic technique. The more sophisticated instrumentation was developed and the resultant advantages were realized. Even more sophisticated equipment is available and could provide further advantages.

Based on these field tests it is our opinion that the laser system is not competitive with our current electronic system.

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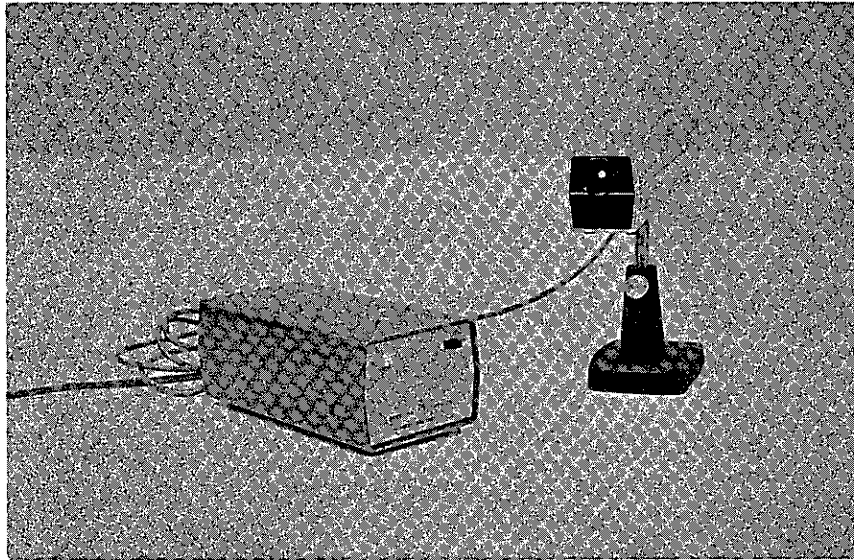


Plate 1. Spectra Physics Model 133 He-Ne Laser and Power Supply.

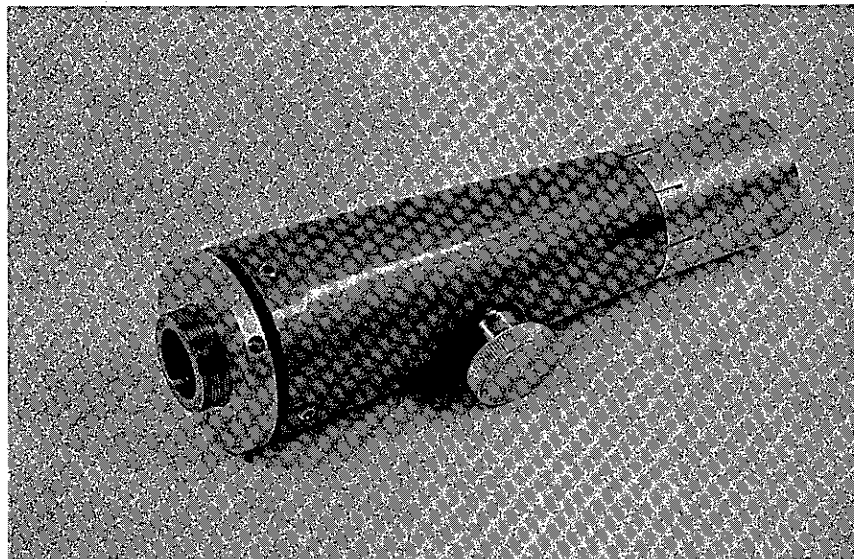


Plate 2. Spectra Physics Model 338 Collimating Telescope.

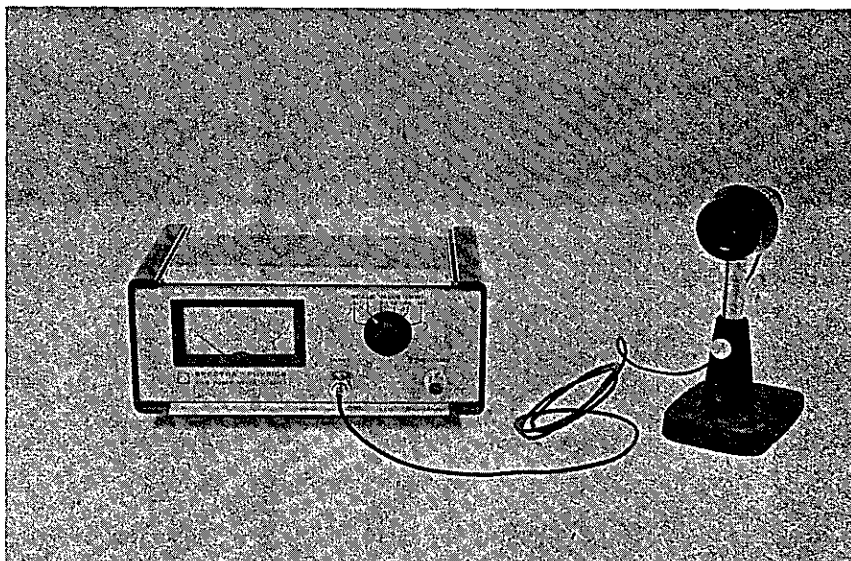


Plate 3. Spectra Physics Model 401C
Power Meter.

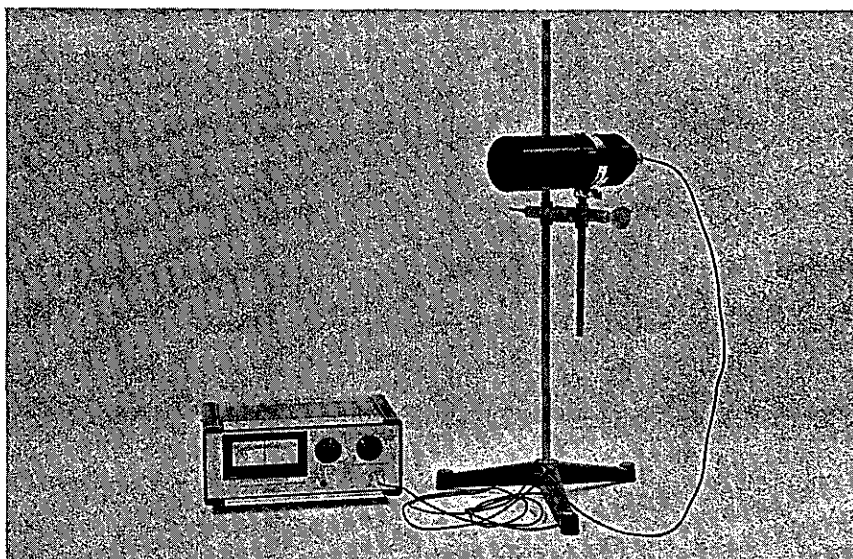


Plate 4. Spectra Physics Model 406
Center Detector.

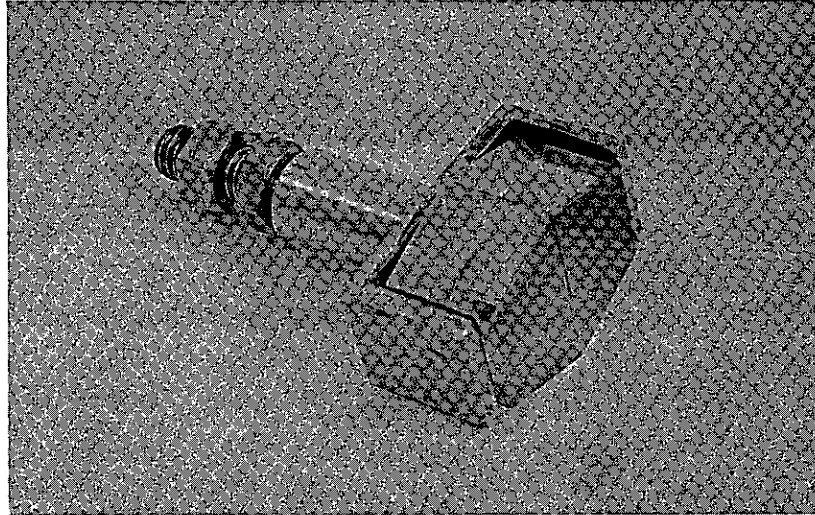


Plate 5. Spectra Physics 515-2
Polarizing Beam Splitter.

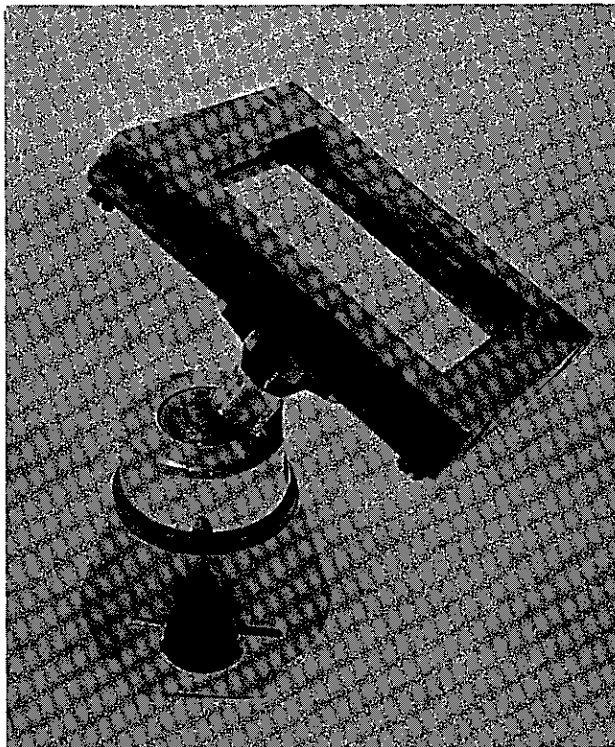


Plate 6. Optics Technology 2" x 2"
Front Surface Laser Reflector
on an adjustable camera base.

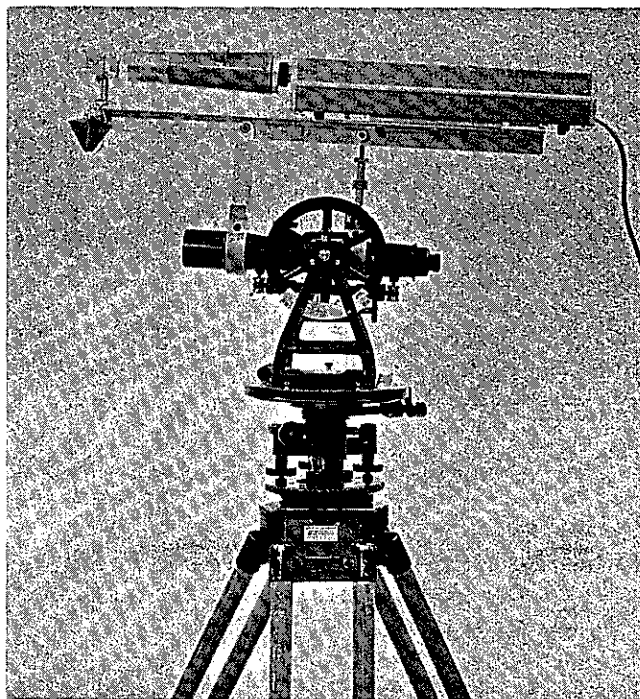


Plate 7. Laser Mounted on Transit.

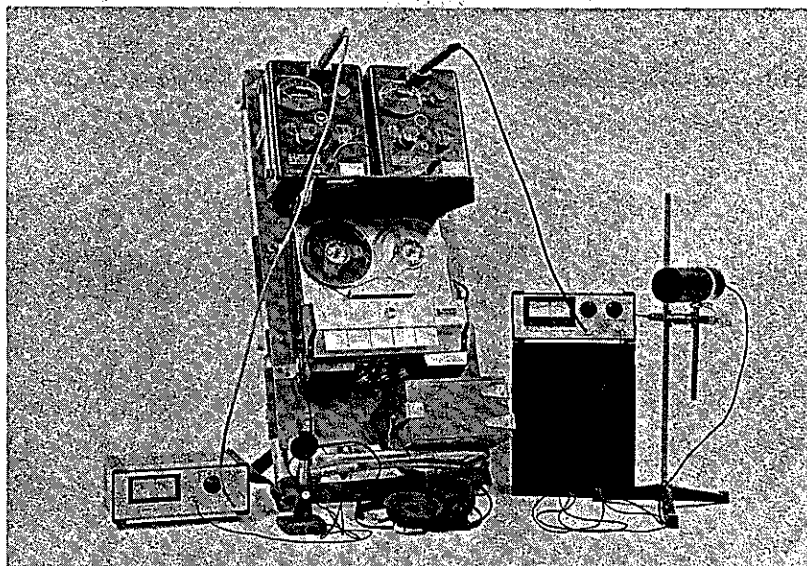


Plate 8. General Radio Sound Level Meters with Power Meter and Center Detector connected to inputs and Roberts 6000 Stereo Tape Recorder connected to outputs.

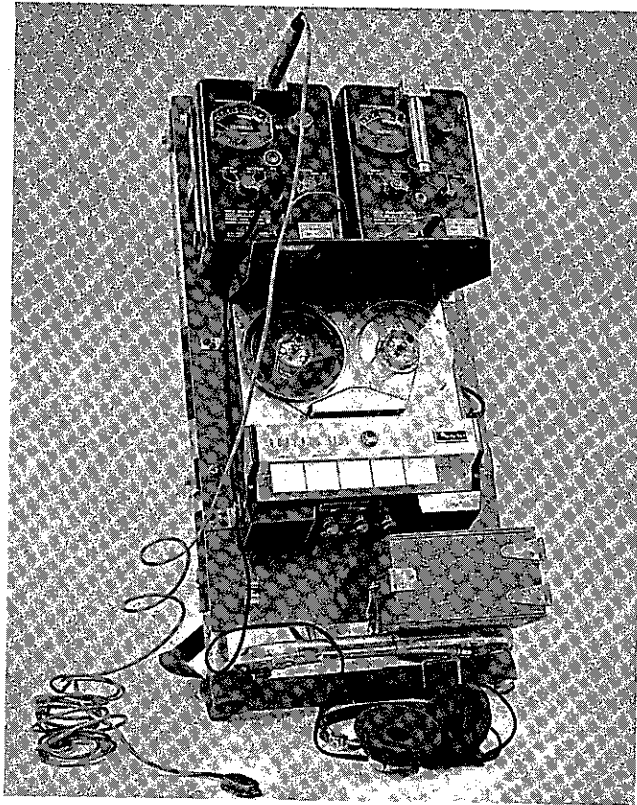


Plate 9. General Radio Sound Level Meter with ElectroVoice 805 contact Microphone connected to input and Roberts 6000 Stereo Tape Recorder connected to output.

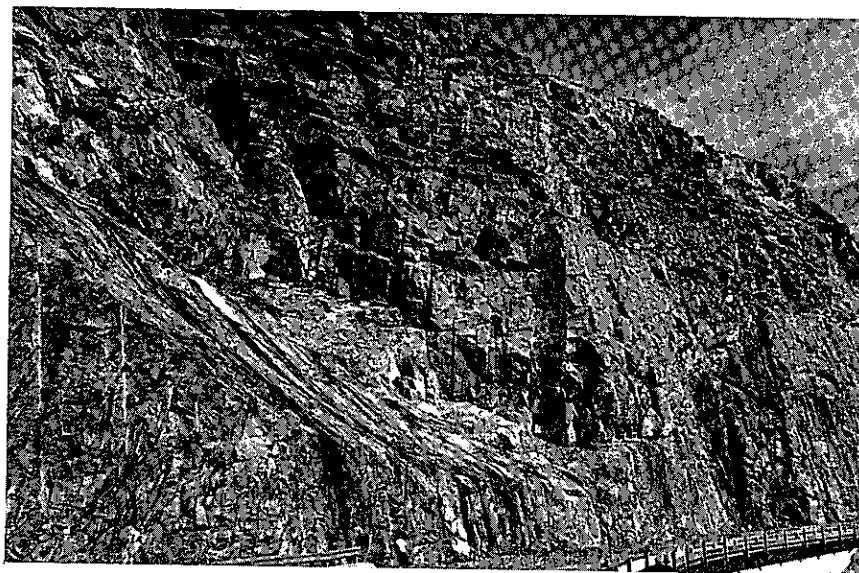


Plate 10. Cut Slope Used for Field Tests.

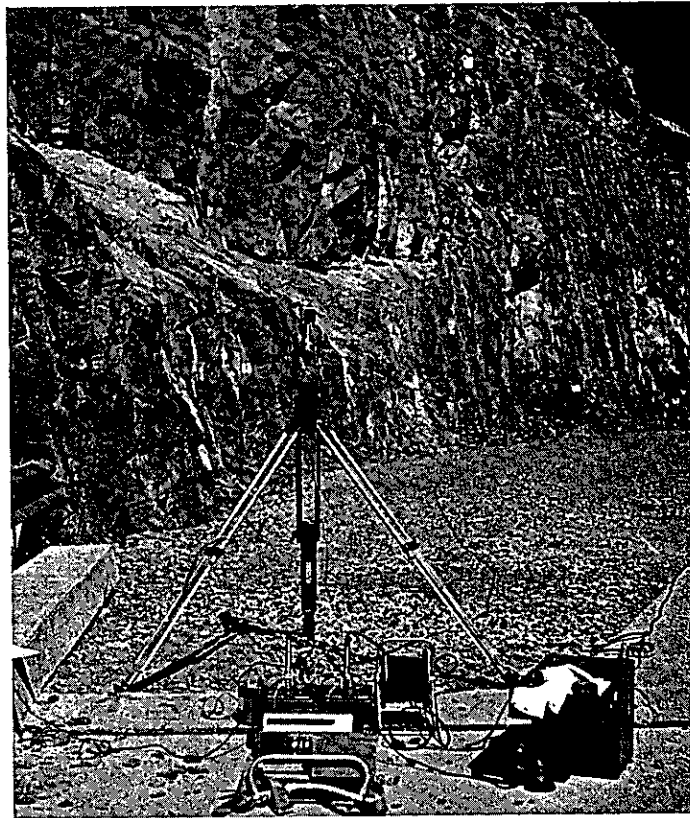


Plate 11. Instrument Set Up
for Field Test



Plate 12. Front Surface Reflector
Attached to Cut Face.